

**SEMI-BLIND TRANSMIT ANTENNA ARRAY DEVICE**  
**USING FEEDBACK INFORMATION AND METHOD THEREOF**  
**IN A MOBILE COMMUNICATION SYSTEM**

5

**PRIORITY**

This application claims priority to an application entitled "Semi-Blind Transmit Antenna Array Device Using Feedback Information and Method Thereof in Mobile Communication System" filed in the Korean Industrial  
10 Property Office on March 8, 2000 and assigned Serial No. 2000-11617, the contents of which are hereby incorporated by reference.

**BACKGROUND OF THE INVENTION**

15

**1. Field of the Invention**

The present invention relates generally to an antenna array device and a method thereof in a mobile communication system, and in particular, to a device and method for forming a transmission beam.

20

**2. Description of the Related Art**

As the number of mobile subscribers drastically increases, the capacity of the mobile communication systems approaches a saturation point. This means that mobile communication systems are in need of more advanced applications to increase the system capacity, particularly the capacity of a forward link for  
25 diverse multimedia services.

The capacity of the forward link can be increased by designing an efficient transmission antenna array system. If the mobile systems use only single transmit antennas, for example dipole antennas, transmission signals are  
30 propagated in all directions. In this situation, when a transmission is performed

toward a desired specific mobile station through a dedicated channel, as opposed to a situation where transmission to all mobile stations is performed using a base station transmission antenna through a common channel, much of the radiation energy except radiation energy for the specified mobile station is useless and the unnecessary radiation energy becomes interference signals to other mobile stations. If the base station transmits a signal only in the direction of the specific mobile station for communication on the dedicated channel, good communication quality is ensured with low transmission power and interference to other mobile stations is decreased. Consequently, the capacity of the forward link increases.

This effect can be achieved using a plurality of antennas. A transmission/reception device related with the antennas is called a transmission antenna array system or transmission smart antenna system. While the transmit antenna array system is applicable to various mobile communication fields, it will be described here in context with CDMA cellular mobile communication for convenience sake.

The structure and operation of a transmit antenna array in the mobile communication system will be described hereinbelow.

FIG. 1 illustrates the transmission beam formation in the transmit antenna array. Referring to FIG. 1, let a transmission signal from a base station be  $s(t)$ . The signal  $s(t)$  is duplicated into a plurality of identical signals, the duplication signals are multiplied by corresponding complex weights in multipliers 111 to 11L, and the resulting signals are transmitted in the air through the respective antennas. A mobile station, using a single antenna, receives the sum of the transmission signals that the base station transmits through the antennas. A direction in which each transmission signal is directed is determined by a weight multiplied by the transmission signal and the geometrical structure of

the transmit antenna array. The reason for assuming that a single antenna is used in the mobile station is that the mobile station does not typically use an antenna array due to limitations of cost, size, and mobility.

- 5 Suppose a linear antenna array has  $L$  antennas as shown in FIG. 1 and each antenna has a complex weight  $w_i$  ( $i = 1, 2, \dots, L$ ), a signal transmitted in a direction  $\theta$  is proportional to

$$\underline{w}^H \underline{a}(\theta) \dots (1)$$

10

where  $\underline{w} = [w_1 w_2 \dots w_L]^T$  is a weight vector,  $\underline{a}(\theta) = [e^{j2\pi \frac{d \sin \theta}{\lambda}} e^{j2\pi \frac{(L-1)d \sin \theta}{\lambda}}]^T$  is an array vector.  $H$  represents Hermitian,  $T$  represents transpose,  $d$  is the distance between antennas, and  $\lambda$  is the wavelength of a carrier frequency. The array vector refers to the relative strength and phase of a signal transmitted from each

15 antenna to a remote destination in the direction  $\theta$ , as expressed in vectors.

$\underline{w}^H \underline{a}(\theta)$  is greatest when  $\underline{w}$  and  $\underline{a}(\theta)$  are in the same direction and  $\underline{w}^H \underline{a}(\theta)$  is 0 when  $\underline{w}$  is at a right angle with  $\underline{a}(\theta)$ . Therefore, the strength of a transmission signal varies according to the transmission direction  $\theta$ . On the same

20 principle, a signal can be transmitted with the greatest strength in a specific direction  $\theta$  by controlling  $\underline{w}$ .

An antenna array is different from a diversity antenna device in that it transmits a signal in a particular direction. The distance between antennas

25 (wavelength order length) is shorter in the antenna array than in the diversity antenna device.

In general, an antenna array is provided to a base station that can

accommodate a plurality of antennas and controls a transmission/reception direction with respect to a mobile station with a single antenna. The antenna array can be considered in two parts: a transmission antenna array and a reception antenna array. The transmission antenna array is focused on for  
5 description by way of example. Yet, the hardware of the antenna array is commonly used for transmission and reception.

A TDD (Time Division Duplex) system, since it uses an identical frequency band for transmission and reception, shows the same characteristics in  
10 transmission and reception and applies a weight vector obtained for a reception antenna array operation to a transmission antenna array operation as well. On the other hand, an FDD (Frequency Division Duplex) system calculates a weight vector separately for a transmission antenna array because a transmission frequency band is separated from a reception frequency band by a coherence  
15 bandwidth or greater. It is to be appreciated that the following description is made on a transmission antenna array system of an FDD system.

Blind transmission is characteristic of transmission antenna arrays that have been developed so far. The blind transmission refers to transmission  
20 without receiving any feedback information of the channel characteristics of a forward link from a mobile station. These transmission antennas operate based on the following reciprocity suppositions between transmission and reception channels.

25       Supposition 1: a forward fading channel and a reverse fading channel arrive at their destinations from the same number of paths and transmission and reception occur in the same path direction.

Supposition 2: if the difference between a transmission frequency band  
30 and a reception frequency band is greater than a coherence bandwidth in an FDD

system, the forward and reverse channels have mutually independent instant fading coefficients but an identical average fading power for the same path.

Raleigh has suggested a blind transmit antenna array for a single fading  
 5 path as shown in FIG. 2 (reference 1: G. G. Raleigh and V. K. Johnes, "Adaptive Antenna Transmission for Frequency Duplex Digital Wireless Communication," in Proc. IEEE ICC, pp. 641-646, Montreal, Canada, June 1997).

A channel vector refers to a collection of the vector-expressed  
 10 characteristics of each antenna in a transmit antenna array with respect to a reception antenna. If we let a forward channel vector be  $\underline{h}$ , then  $\underline{h} = \beta \underline{a}(\theta)$ .  $\beta$  is a fading coefficient independent of a reverse fading coefficient according to supposition 2,  $\theta$  is a transmission direction from a base station to a mobile station, which the base station knows from a reverse signal by supposition 1 without  
 15 receiving forward fading feedback information from the mobile station, and  $\underline{a}(\theta)$  - corrected is an array vector for the direction  $\theta$ .

The base station transmits a transmission message  $s(t)$  by forming a beam with a weight vector  $\underline{w}$  and the message  $s(t)$  arrives at the mobile station  
 20 on a forward channel  $\underline{h}$ . The received signal  $r(t)$  can be expressed by

$$r(t) = \underline{h}^T \underline{w} s(t) + n(t) \quad \dots \dots (2)$$

where  $n(t)$  is additive white Gaussian noise (AWGN).

25

According to a matching filter theory, an optimal weight vector that brings a maximal output SNR at a receiving end of the mobile station is

$$\underline{w} = \sqrt{P} \frac{\underline{h}^*}{\|\underline{h}\|} \quad \dots \quad (3)$$

where P is the transmission power of the base station, \* is a conjugate operator, and  $\|\cdot\|$  is the norm of a corresponding vector. By applying the relationship of

5  $\underline{h} = \beta \underline{a}(\theta)$  to Eq. 3,

$$\underline{w} = \sqrt{P} \frac{\underline{a}^*(\theta)}{\|\underline{a}(\theta)\|} \quad \dots \quad (4).$$

10 From Eq. 4, it is noted that an optimal weight vector is set using only the transmission direction  $\theta$  known from a reverse signal by supposition 1 without a fading coefficient. Because a single path is assumed, not a fading coefficient but an array vector is obtained.

15 Now, a description of the transmission antenna array suggested by Raleigh will be given. Referring to FIG. 2, a transmission message is propagated in the air via an antenna array 203 by a beam formed in a specific transmission direction in a transmission beam generator 202. A reverse processor 205 processes a reverse channel signal received via the antenna array 203. An array

20 vector calculator 207 divides reversely received signals for each path through a path divider in a rake receiver of the reverse processor 205 and calculates a direction (array vector) on the basis of direction information of the received signals. A weight vector calculator 209 calculates a weight vector using the array vector and outputs the array vector to the transmission beam generator 202. The

25 transmission beam generator 202 controls generation of a transmission beam by assigning a weight to a transmission signal that is to be output via a corresponding antenna based on the weight vector.

The above transmission antenna array system estimates the reception direction of a signal received via the antenna array 203, calculates a weight vector (array vector) for the transmission antenna array based on the estimated direction information, and then forms a transmission beam using the weight vector, for transmission.

Despite the advantage of simple structure, the Raleigh transmission antenna array using a single path is not feasible for a multi-path system.

10

Thompson has suggested a blind transmission antenna array with a multi-fading path as shown in FIG. 3 (reference 2: J. S. Thompson, J. E. Hudson, P. M. Grant, and B. Mulgrew, "CDMA Downlink Beamforming for Frequency Selective Channels," PIMRC'99, B2-3, Osaka, Japan, September 1999).

15

In the case of a multi-fading path (M paths), a reception direction for each path must be estimated from an input signal to form a forward transmission beam as is done in the case of a single path. If a reception direction (a transmission direction according to supposition 1) for an  $i$ th fading path ( $i = 1, 2, \dots, M$ ) is  $\theta_i$ , a transmission beam for the  $i$ th fading path is formed in the direction of  $\theta_i$ . The issue is how to determine weights (different from weight vectors). Considering this issue, an optimal weight vector is determined in the following way.

20

Assuming that the base station transmits a transmission message by forming a transmission beam with a weight vector  $\underline{w}$  and it arrives at the mobile station from three different paths on a forward channel, a signal  $r(t)$  received at the mobile station can be expressed by

$$r(t) = \underline{h}_1^T \underline{ws}(t - \tau_1) + \underline{h}_2^T \underline{ws}(t - \tau_2) + \underline{h}_3^T \underline{ws}(t - \tau_3) \quad \dots (5)$$

where  $\tau_i$  is a propagation delay for an  $i$ th path and  $\underline{h}_i$  is a channel vector for an  $i$ th path. Similarly to a single path, with respect to the transmission direction  $\theta_i$  and a fading coefficient  $\beta_i$ ,  $\underline{h}_i$  is as follows. Herein, the fading coefficient  $\beta_i$  means a value including a phase and a size value of the received signal.

$$\underline{h}_i = \beta_i \underline{a}(\theta_i) \quad \dots (6)$$

10

According to the matching filter theory, an optimal weight vector that brings a maximum output SNR at a receiving end of the mobile station is

$$\underline{w}^* = \arg \max_{\underline{w}} \underline{w}^H H^H H \underline{w} \text{ subject to } \|\underline{w}\|^2 = P$$

15

$$\text{where } H = [\underline{h}_1 \underline{h}_2 \underline{h}_3]$$

..... (7)

where  $P$  is transmission power,  $\underline{w}^*$  is an optimal weight vector, and  $\underline{h}_1, \underline{h}_2, \underline{h}_3$  are channel vectors for the paths. The solution of Eq. 7 is set as a maximum unique vector corresponding to the maximum unique value of a transmission correlation matrix  $H^H H = \sum_{i=1}^3 |\beta_i|^2 \underline{a}(\theta_i) \underline{a}(\theta_i)^H$ .

From the foregoing, it can be noted that the base station needs to know a fading coefficient  $\{\beta_i\}$  as well as a transmission direction  $\{\theta_i\}$  in order to achieve the optimal weight vector. On the contrary, the base station need not know a fading coefficient to form a transmission beam for a single fading path. In an



FDD environment, the instant fading coefficient of a reverse channel is different from that of a forward channel. Thus, it is no use analyzing a received reverse signal to obtain the instant fading coefficient of the forward channel.

- 5 By replacing  $H^H H$  of Eq. 7 with an expectation  $E[H^H H]$ , Thompson proposed a semi-optimal weight vector given by

$$E[H^H H] = \sum_{i=1}^3 E[|\beta_i|^2] \underline{a}(\theta_i) \underline{a}(\theta_i)^H \dots (8).$$

10

In Eq. 8, the transmission direction  $\{\theta_i\}$  (the array vector  $\{\underline{a}(\theta_i)\}$ ) is estimated from a received reverse signal according to supposition 1 and  $E[|\beta_i|^2]$  is also estimated from the received reverse signal according to supposition 2.

- 15 This is blind beam formation without the need of receiving feedback information about a fading coefficient from a mobile station. However, the blind beam formation has a slightly lower performance than the non-blind beam formation using an optimal weight vector calculated by Eq. 7.

- 20 FIG. 3 is a block diagram of the transmit antenna array device suggested by Thompson. Referring to FIG. 3, a transmission message is formed into a beam by a transmission beam generator 302 of a forward processor 301 and propagated in the air in a particular direction via an antenna array 303. A reverse processor 305 processes a reverse channel signal received via the antenna array
- 25 303. A forward fading power calculator 307 estimates a fading coefficient of the received signal for each path, which is obtained by the reverse processor 305 in the course of processing the received signals and calculates the average power of the estimated fading coefficients. The reverse average fading power is calculated

based on supposition 2. An array vector calculator 309 divides the received signals for each path through a path divider in a rake receiver of the reverse processor 305 and calculates the input direction (array vector) of the received signal from the received signals. A transmission correlation matrix calculator 311  
 5 obtains a transmission correlation matrix using the average fading power and the array vector and a weight vector calculator 313 calculates a weight vector using the transmission correlation matrix. The transmission beam generator 302 assigns a weight to a transmission signal that will be output via a corresponding antenna according to the weight vector received from the weight vector  
 10 calculator 313, to thereby control formation of the transmission beam.

According to the Thompson transmit antenna array system, a reception antenna array first estimates the input direction (array vector) of a received signal. Then, the reception antenna array estimates a fading coefficient of the received  
 15 signal for each path and calculates the average power of the fading coefficients. Based on the direction information and the average fading power information, a weight vector for a transmission antenna array is calculated. Finally, a transmission beam is formed using the weight vector and transmitted.

20 While the Thompson antenna array structure can be used as a transmission antenna array system in a multi-path environment, the use of an average fading power makes it impossible to calculate a precise weight vector. That is, the average fading power is used in calculating a forward fading power instead of an instant fading power. The average fading power is calculated based  
 25 on supposition 2. A reverse average fading power is calculated from a received signal for use as an average forward fading power. The limitation of the Thompson antenna array in calculating a precise weight vector decreases the performance of the antenna array system.

It is, therefore, an object of the present invention to provide a device and method for forming a transmission beam by calculating an optimal weight vector based on forward fading information feedback from a mobile station in a base  
5 station using a forward antenna array in a mobile communication system.

It is also an object of the present invention to provide a device and method for estimating forward fading information from a signal received on a forward channel and transmitting the forward fading information to a base station  
10 on a reverse channel in a mobile station of a mobile communication system using an antenna array.

It is another object of the present invention to provide a transmit antenna array device and a method thereof suitable for a mobile communication system  
15 where a feedback delay time is short and a mobile station roams at a movement speed that is not greatly changed.

It is a further object of the present invention to provide a transmit antenna array device and a method thereof in which a current forward fading  
20 coefficient is estimated from previous forward fading information fed back from a mobile station in a mobile communication system where a feed back delay time is great and the mobile station roams at a movement speed that is not greatly changed.

25 It is still another object of the present invention to provide a transmit antenna array device using a mixed forward beam formation scheme where a basic type and a blind forward beam formation type are selectively used according to the movement speed of a mobile station and a method thereof when a feedback delay time is short in a mobile station with multiple signal paths.

30

It is yet another object of the present invention to provide an antenna array device using a mixed forward beam formation scheme where a prediction type and a blind forward beam formation type are selectively used according to the movement speed of a mobile station and a method thereof when a feedback  
5 delay time is rather long in a mobile station with multiple signal paths.

The foregoing and other objects of the present invention are achieved by a transmit antenna array device with at least two antennas and a method thereof in which a transmission beam is formed appropriately based on a weight vector  
10 to be transmitted to a specific mobile station in a mobile communication system. For this purpose, a base station device has a reverse processor for processing a reverse signal received through the antenna array, a forward fading information extraction unit for extracting forward fading information from the received reverse signal, a beam formation controller for generating a weight vector for  
15 formation of a transmission beam using the forward fading information and the received reverse signal, and a forward processor having a transmission beam generator for generating a transmission beam for a transmission message based on the weight vector. A mobile station device has a forward processor for processing a received forward signal, a forward fading estimator for estimating  
20 forward fading information of the forward signal for each path, a forwarding fading encoder for combining the estimated forward fading information and encoding the combined forward fading information, and a reverse processor for multiplexing the encoded forward fading information with a transmission message and feeding back the forward fading information in the multiplexed  
25 signal to a base station.

### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present  
30 invention will become more apparent from the following detailed description

when taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates transmission beam formation in a general transmit antenna array;

FIG. 2 is a block diagram of a conventional transmit antenna array system suggested by Raleigh;

FIG. 3 is a block diagram of a conventional transmit antenna array system suggested by Thompson;

FIG. 4 is a block diagram of a transmit antenna array system in a mobile communication system according to the present invention;

FIG. 5 is a block diagram of an embodiment of the transmit antenna array system (a basic type) according to the present invention;

FIG. 6 is a block diagram of another embodiment of the transmit antenna array system (a prediction type) according to the present invention;

FIG. 7 is a block diagram of a third embodiment of the transmit antenna array system (a basic mixed type) according to the present invention;

FIG. 8 is a block diagram of a fourth embodiment of the transmit antenna array system (a prediction mixed type) according to the present invention;

FIG. 9 is a flowchart illustrating the whole operation of the transmit antenna array system according to the present invention;

FIG. 10 is a flowchart illustrating a forward fading power calculation procedure in the first embodiment of the transmit antenna array system according to the present invention;

FIG. 11 is a flowchart illustrating a forward fading power calculation procedure in the second embodiment of the transmit antenna array system according to the present invention;

FIG. 12 is a flowchart illustrating a forward fading power calculation procedure in the third embodiment of the transmit antenna array system according to the present invention; and

FIG. 13 is a flowchart illustrating a forward fading power calculation procedure in the fourth embodiment of the transmit antenna array system

according to the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 Preferred embodiments of the present invention will be described hereinbelow with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail since they would obscure the invention in unnecessary detail.

10 The present invention uses an instant forward fading coefficient instead of an average reverse fading coefficient in order to form a forward beam with improved performance as compared to the conventional antenna arrays systems. A base station, being a transmitting side, does not know the forward fading coefficient indicating channel characteristics in advance. Thus, according to the  
15 preferred embodiment of the present invention, a mobile station extracts the forward fading coefficient from the forward channel information and feeds it back on a reverse channel to the antenna array system. Herein, the reverse channel for transmitting forward channel information may be an existing reverse channel or a separately designated reverse channel. If an existing reverse  
20 channel transmits the forward fading coefficient, it may be a control channel. Then, a control channel message can be re-formatted to include the forward channel information.

While the conventional antenna array systems using an average reverse  
25 fading coefficient rely on blind beam formation, an antenna array system according to the present invention is a semi-blind beam formation scheme in that a base station receives feedback information about a forward fading coefficient from a mobile station.

30 The transmit antenna array system of the present invention relying on

semi-blind beam formation will be described below.

Assuming that a fading channel is propagated in  $M$  different paths between a base station and a specific mobile station, and the base station transmits a transmission message  $s(t)$  to the mobile station using a transmit antenna array including  $L$  antennas, a signal  $r(t)$  received at the mobile station is

$$r(t) = \sum_{i=1}^M \underline{h}_i^T \underline{w} s(t - \tau_i) + n(t) \quad \dots\dots (9)$$

10 where  $\underline{w}$  is a weight vector assigned to the transmit antenna array,  $n(t)$  is AGWN,  $\tau_i$  is a propagation delay for an  $i$ th path, and  $\underline{h}_i$  is a channel vector for the  $i$ th path, given by

$$\underline{h}_i = \beta_i \underline{a}(\theta_i) \quad \dots\dots (10).$$

As noted from Eq. 10, the channel vector  $\underline{h}_i$  is a function of a fading coefficient  $\beta_i$ , a transmission direction  $\theta_i$ , and an array vector  $\underline{a}(\theta_i)$  for the  $i$ th path.

20 The signal  $r(t)$  received at the mobile station on a forward channel can be divided into path components by a path divider and a collection of the path components  $\underline{r}$  is expressed as

$$\begin{aligned} \underline{r} &= \begin{bmatrix} \underline{h}_1^T \underline{w} s(t - \tau_1) \\ \underline{h}_2^T \underline{w} s(t - \tau_2) \\ \vdots \\ \underline{h}_M^T \underline{w} s(t - \tau_M) \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_M \end{bmatrix} \\ &= H \underline{w} s + \underline{n} \end{aligned} \quad \dots (11).$$

4B  
A3

In Eq. 11,  $H = [\underline{h}_1, \underline{h}_2 \dots \underline{h}_M]^T$ ,  $\underline{n} = [n_1, n_2 \dots n_M]^T$ , and  
 5  $s(t - \tau_1) = s(t - \tau_2) = \dots = s(t - \tau_M)$ . Here,  $s(t - \tau_1)$ ,  $s(t - \tau_2)$ , ...,  $s(t - \tau_M)$  are  
 termed  $s$ . It is assumed that the length of a symbol in the received message is  
 greater than any path delay.

Applying a matching filter theory to Eq. 11, a determination variable, a  
 10 matching filter output is given by

$$\begin{aligned} \hat{s} &= (H \underline{w})^H \underline{r} \\ &= \underline{w}^H H^H H \underline{w} s + \underline{w}^H H^H \underline{n} \end{aligned} \quad \dots (12)$$

and an SNR for the determination variable is  
 15

$$\gamma = \frac{\underline{w}^H H^H H \underline{w}}{\sigma_n^2} \quad \dots (13)$$

where  $\sigma_n^2$  is the power of the AGWN.

20 The optimal weight vector  $\underline{w}$  maximizes the SNR of the matching filter  
 output at a receiver on the assumption that the transmission power is  $P$ . From the  
 foregoing, a transmission correlation matrix can be obtained by



$$\begin{aligned}
 G &= H^H H \\
 &= \sum_{i=1}^M |\beta_i|^2 \underline{a}(\theta_i) \underline{a}(\theta_i)^H
 \end{aligned}
 \dots\dots(14).$$

Therefore, calculation of the optimal weight vector falls into calculation of a maximum eigen-vector corresponding to a maximum eigen-value of the above transmission correlation matrix in the end.

The transmission direction  $\theta_i$ , that is, the transmission array vector  $\underline{a}(\theta_i)$  in Eq. 14 is known by estimating the reception direction of an input signal according to supposition 1 in the base station. However, information about the forward fading coefficient  $\beta_i$ , that is, the forward fading power  $|\beta_i|^2$ , cannot be obtained from the input signal but fed back from the mobile station on a reverse channel.

In the present invention, the base station receives feedback information about a forward fading coefficient calculated by the mobile station on a separately designated reverse channel. By the forward fading coefficient, the base station forms the transmission correlation matrix  $G$  of Eq. 14 and calculates the maximal unique vector of the transmission correlation matrix  $G$ , so that it calculates a weight vector for use in forming an intended forward beam.

To reduce the feedback constraint of the mobile station by half, the base station may receive information about fading severity or fading power in a real value instead of a fading coefficient in a complex value from the mobile station. While the present invention is described in context with formation of a transmission beam based on feedback information of a fading coefficient, the same effect can be achieved by receiving the fading severity or fading power.

The mobile station estimates an input signal component for each path through a path divider and a fading estimator as in Eq. 11. If noise components are excluded from Eq. 11 for convenience sake,

5

$$\underline{h}_i^T \underline{w} = \beta_i \underline{a}(\theta_i)^T \underline{w} \quad \dots (15)$$

the fading estimator functions to estimate not the forward fading coefficient itself  
 10 but the product of the forward fading coefficient, the array vector, and the weight vector as shown in Eq. 15. Although it is ideal that the mobile station transmits the forward fading coefficient only on a reverse fading channel, in reality, the base station receives information including the forward fading coefficient, the array vector, and weights. Hereinbelow, the information including the forward  
 15 fading coefficient, the array vector, and the weights will be referred to as “fading information”. The forward fading coefficient can be replaced by a forward fading severity. The following description is based on a calculation of a weight vector using a forward fading coefficient. Therefore, the fading estimator in the base station must extract only the forward fading coefficient  $\beta_i$  from the feedback  
 20 information received from the mobile station.

The forward fading coefficient is extracted by two methods. One is to use an omnidirectional beam with  $\underline{a}(\theta_i)^T \underline{w}$  independent of  $\theta_i$  as a transmission beam so that an estimated value of the fading estimator becomes a function of the  
 25 forward fading coefficient  $\beta_i$  only. The mobile station may feed back this value on a separately designated reverse channel. The other method is to extract the forward fading coefficient  $\beta_i$  using a known weight vector  $\underline{w}$  used in transmitting a forward signal to the mobile station and  $\theta_i$  estimable from a received signal by simple arithmetic operation in the base station, upon receipt of feedback

information of an estimated input signal component for each path,  $\{\beta_i \underline{a}(\theta_i)^T \underline{w}\}$  on a specific reverse channel from the mobile station.

A time delay may be involved in feeding back the forward fading coefficient  $\beta_i$ . If a time delay as long as a unit time  $D$ , for example a slot, exists between the mobile station and the base station, inevitably, a current forward fading coefficient must be estimated from previously fed back forward fading coefficients. This problem can be overcome by linear prediction.

Now a description of the linear prediction for estimating a forward feedback coefficient received with a time delay will be given.

Suppose  $\beta_i[k]$  is a forward fading coefficient for an  $i$ th path at a  $k$ th time point (the present time point). By a linear combination of  $V$  fading coefficients,  $\beta_i[k-D], \beta_i[k-D-1], \dots, \beta_i[k-D-V+1], \beta_i[k]$  is estimated to

$$\hat{\beta}_i[k] = \sum_{v=0}^{V-1} b_v \beta_i[k-D-v] \quad \dots (16)$$

where if a definition is given as  $\underline{b} = [b_0, b_1, \dots, b_{V-1}]^T$  and  $\underline{\beta} = [\beta_i[k-D], \beta_i[k-D-1], \dots, \beta_i[k-D-V+1]]^T$ , the equation 16 is

To obtain a coefficient vector  $\underline{\beta}$ , a value  $\underline{\beta}$  which allows  $E(\beta(k) - \hat{\beta})^2$  to be a minimum value, should be calculated. Thus, the coefficient vector  $\underline{b}$  is

$$\underline{b} = R^{-1} \underline{p} \quad \dots (17)$$

according to the linear prediction method.

In Eq. 17,  $R = E[\underline{\beta}\underline{\beta}^H]$  and  $\underline{p} = [\beta_i[k]\underline{\beta}^*]$ . A correlation coefficient between delayed fading coefficients, needed to calculate Eq. 17 is calculated by

$$E[\beta_i[k]\beta_i^*[k-u]] = \sigma_\beta^2 J_0(2\pi f_D T u) \quad \dots\dots (18)$$

where  $\beta_i[k]$  is a Fading Coefficient received at a  $k$ th time point on a  $i$ th path,  $\sigma_\beta^2 = E[|\beta_i|^2]$ ,  $f_D$  is a Doppler frequency,  $J_0(\cdot)$  is a Bessel function of the first kind of order zero, and  $T$  is the length of a unit time.

10 If the base station receives feedback only information of a fading severity being a real value instead of a fading coefficient being a complex value from the mobile station, it is advantageous to reduce the number of bit sent to a reverse channel. If  $|\beta_i[k]|$  is a forward fading severity for an  $i$ th path at a  $k$ th time point (the present time point), it is estimated by a linear combination of  $V$  fading  
15 severities fed back from the mobile station before the unit time  $D$ ,  $|\beta_i[k-D]|$ ,  $|\beta_i[k-D-1]|$ , ...,  $|\beta_i[k-D-V+1]|$ . Thus, an average of the forward fading coefficient is 0 but average of the fading severity for obtaining an absolute value is not 0. In view of the foregoing, the above step using a fading coefficient being a complex value cannot be applied without modification.

20 However, the above procedure is not applicable because the average of the forward fading severities is not zero. A zero-average forward fading severity can be defined as

$$\delta_i = |\beta_i| - E[|\beta_i|] \quad \dots\dots (19)$$

and  $|\beta_i[k]|$  is estimated by a linear combination of  $\delta_i[k-D]$ ,  $\delta_i[k-D-1]$ , ...,

$\delta_i[k-D-V+1]$  as

$$\hat{\beta}_i[k] = \sum_{v=0}^{V-1} d_v \delta_i[k-D-v] + E[|\beta_i|] \quad \dots (20)$$

5 where if  $\underline{d} = [d_0 d_1 \dots d_{V-1}]^T$  and  $\underline{\delta} = [\delta_i[k-D] \delta_i[k-D-1] \dots \delta_i[k-D-V+1]]^T$ , the coefficient vector  $\underline{d}$  is calculated by

$$\underline{d} = R^{-1} \underline{p} \quad \dots (21)$$

10 according to the linear prediction method.

In Eq. 21,  $R = E[\underline{\delta} \underline{\delta}^T]$  and  $\underline{p} = E[\delta_i[k] \underline{\delta}]$ . A correlation coefficient between delayed zero-average fading coefficients, needed to calculate Eq. 21 is calculated by

15

$$E[\delta_i[k] \delta_i[k-u]] = \sigma_\delta^2 J_0^2(2\pi f_D T u) \quad \dots (22)$$

where  $\sigma_\delta^2 = E[|\delta_i|^2]$ ,  $f_D$  is a Doppler frequency,  $J_0(\cdot)$  is a Bessel function of the first kind of order zero, and  $T$  is the length of a unit time.  $E[\beta_i]$  is obtained by  
20 time-averaging forward fading severity sample values for each path.

As the mobile station travels at a higher speed, the Doppler frequency increases and channel characteristics are quickly changed. As a result, the reliability of the present forward fading coefficient estimated by the linear  
25 prediction is decreased and the whole system performance is deteriorated. In this case, the whole system performance may improve by using an average reverse channel fading coefficient based on blind transmission rather than the current

forward fading coefficient based on linear prediction. That is, first, a Doppler frequency threshold is set to a predetermined value. Then, when the measured Doppler frequency is below the threshold, which means low mobile speed, the linear prediction method is selected since the linear prediction is regarded as  
 5 reliable. Otherwise, the blind transmission method is selected instead of the linear prediction method since the linear prediction is regarded as unreliable for high mobile speed. The selective use of the linear prediction method and the blind transmission method is called a mixed method.

10        Formation of a transmission beam can be implemented in four embodiments according to time delay and channel changes. The four embodiments of the present invention are termed a basic type, a prediction type, a basic mixed type, and a prediction mixed type, respectively. Commonly in the four embodiments, a mobile station feeds back forward fading information to a  
 15 base station and the base station generates a weight vector based on the forward fading feedback information to efficiently form a transmission beam. The four embodiments are very similar in structure and operation but they differ in the essence of a transmission beam formation algorithm, the configuration of a transmission correlation matrix.

20

FIG. 4 is a block diagram of a transmit antenna array system for a base station in a mobile communication system according to the present invention. A mobile station is also shown in the drawing. The transmit antenna array system receives a forward fading coefficient from the mobile station and calculates an  
 25 optimal weight vector based on the forward fading coefficient to efficiently form a transmission beam. The mobile station, after receiving a forward signal from the base station, estimates the forward fading coefficient and transmits it to the base station on a predetermined reverse channel. A forward fading severity can be used instead of the forward fading coefficient. FIG. 9 is a flowchart  
 30 illustrating an operation between the base station and the mobile station shown in

FIG. 4.

Referring to FIG. 4, the base station is comprised of a forward processor 400, an antenna array 405, a reverse processor 410, a forward fading information  
5 extraction unit 421, and a beam formation controller 420.

The forward processor 400 subjects a transmission signal to encoding and modulation, and upconverts the frequency of the modulated signal to an RF signal. A transmission beam generator 403 forms a beam for the forward  
10 transmission signal. The forward processor 400 includes an encoder 401, a modulator 402, the transmission beam generator 403, and an RF module 404.

The antenna array 405 includes L antennas and propagates a beam in a direction determined by the transmission beam generator 403 of the forward  
15 processor 400.

The reverse processor 410 subjects an RF signal received via the antenna array 405 to downconversion, demodulation, and decoding. The reverse processor 410 includes an RF module 411, a rake receiver 412 with M fingers, a  
20 path divider, and a path combiner, and a decoder 413.

The forward fading information extraction unit 421 functions to extract a forward fading coefficient from the fading information of a signal received from the rake receiver 412 of the reverse processor 410. Here, a forward fading  
25 severity may be included in the fading information instead of the forward fading coefficient.

The beam generation controller 420 receives the forward fading coefficient from the forward fading information extraction unit 421, and array  
30 vector, a reverse fading information and a Doppler frequency information output

from the rake receiver 412 and generates a weight vector to control formation of the transmission beam. The beam formation controller 420 has a forward fading power calculator 422, an array vector calculator 423, a transmission correlation matrix calculator 424, and a weight vector calculator 425. As many forward  
5 fading power calculators 422 and array vector calculators 423 as signal paths must be provided. Therefore, it is desirable to configure the forward fading power calculator 422 and the array vector calculators 423 corresponding to the respective fingers of the rake receiver 412. The beam formation controller 420 varies in the four embodiments of the present invention.

10

A reception beam generator (not shown) is disposed before or after a demodulator in each finger of the rake receiver 412. The modulator 402 may be exchanged with the transmission beam generator 403 in position within the forward processor 400. Since the embodiments of the present invention are  
15 implemented on the same principle, the present invention should be considered to incorporate the above possibilities therein.

The transmit antenna array system of the base station controls formation of a transmission beam according to forward fading information fed back from  
20 the mobile station. To allow for this operation, the mobile station receives a forward link signal from the base station, estimates the forward fading information, and feeds back the estimated fading information the base station, which will be described referring to FIG. 4.

25 An antenna array system is not commonplace in mobile stations. Therefore, the mobile station shown in FIG. 4 uses a single antenna 431.

A forward processor 430 in the mobile station processes a signal received from the base station on a forward link. The forward processor 430  
30 includes an RF module 432, a rake receiver 433 with M fingers, a path divider,



and a path combiner, and a decoder 434.

A reverse processor 440 subjects a transmission signal to encoding and modulation, and transmits a modulated signal to the base station on a reverse  
5 channel. The reverse processor 440 includes an encoder 441, a multiplexer 442, a modulator 443, and an RF module 444.

A forward processor 450 estimates forward fading information from the received forward link signal, encodes the estimated forward fading information,  
10 and feeds back the encoded forward fading information on a particular reverse channel. The forward processor 450 includes a forward fading estimator 451 and a forward fading encoder 452. Here, "fading information" estimated by the forward fading estimator 451 refers to information containing a weight vector and an array vector for beam formation as well as a fading coefficient for a multi-  
15 path fading channel. As shown in Eq. 15, the fading information contains the forward fading coefficient  $\beta_i$ , the array vector  $\underline{a}(\theta_i)$ , and the weight  $\underline{w}$ . This is the difference between the fading information of the present invention and fading information conventionally used in the case when a smart antenna is not employed.

20

The forward processors 400 and 430 and the reverse processors 410 and 440, except for the transmission beam generator 403, are the same in structure as the counterparts used in a general CDMA communication system.

25 Upon receipt of a transmission message through the encoder 401 and the modulator 402 in the base station, the transmission beam generator 403 forms a transmission beam with use of an appropriate initial weight vector  $\underline{w}[0]$  received from the weight vector calculator 425. The transmission beam is radiated into the air via the RF module 404 and the antenna array 405.

The mobile station receives the forward signal via the single antenna 431 and the RF module 432, divides, demodulates, and combines the forward signal according to the paths in the rake receiver 433, and recovers a received message  
5 in the decoder 434.

The forward signal received at the mobile station is given as Eq. 9. The channel vector  $\underline{h}_i$  for each path in Eq. 9 includes information about a forward fading coefficient and an array vector as shown in Eq. 10. Therefore, forward  
10 fading information estimated by the forward fading estimator 451 includes a forward fading coefficient, an array vector, and a weight as shown in Eq. 15. Since what the base station needs is  $\beta_i$ , the forward fading estimator 451 may extract only the forward fading coefficient from the fading information and transmits it. Or the forward fading estimator 451 may estimate a forward fading  
15 severity being a real value instead of the forward fading coefficient being a complex value. The forward fading coefficient facilitates linear prediction, whereas feedback of the estimated forward fading coefficient to the base station is a constraint to the mobile station. On the other hand, despite the advantage of a relatively small feedback constraint, the forward fading severity makes the  
20 linear prediction quite complicated. Accordingly, the forward fading coefficient or the forward fading severity can be selected adaptively to the situation.

The forward fading encoder 452 encodes the estimated forward fading information and feeds the encoded signal to the multiplexer 442. The encoded  
25 forward fading information may be transmitted on a reverse link channel separately designated or it may be inserted into a modified control channel frame and transmitted on an existing control channel.

In operation, the forward fading estimator 451 in the mobile station

estimates a fading coefficient for each path from a forward signal received from the rake receiver 433. The forward fading encoder 452 collects all forward fading information and encodes the forward fading information. The multiplexer 442 multiplexes the encoded forward fading information with an encoded  
 5 transmission message and the resulting signal is radiated into the air via the modulator 443, the RF module 444, and the single antenna 431.

Though the mobile station returns to a reception mode, transmission and reception are virtually concurrent in the mobile station and the above procedure  
 10 is repeated. It is assumed here that a delay of a unit time  $D$  (usually a slot) is involved between forward transmission and reverse transmission.

The base station receives the reverse signal via the antenna array 405 and the RF module 411 and subjects the received reverse signal to demodulation and  
 15 decoding through the rake receiver 412 and the decoder 413. During this operation, a reverse beam generator in the rake receiver 412 generates a reverse beam, which will not be described here.

The beam formation controller 420 of the base station calculates weight  
 20 vectors for formation of a next transmission beam. The following procedure is common to the first and fourth embodiments of the present invention.

The forward fading information extraction unit 421 extracts forward fading feedback information from the intermediate output of the rake receiver  
 25 412. The forward power calculator 422 calculates a forward fading power  $\{p_i\}$  for each path, which is really applied to a transmission antenna array, based on the extracted forward fading information and reverse fading information for each path and Doppler frequency information obtained during processing the reverse signal in the rake receiver 412. Simultaneously, the array vector calculator 423

calculates an array vector  $\{a(\theta_i)\}$  for each path based on information about reception directions obtained during the reverse signal processing in the rake receiver 412.

- 5        The transmission correlation matrix calculator 424 calculates a transmission correlation matrix  $G = \sum_{i=1}^M p_i a(\theta_i) a(\theta_i)^H$  using the forward fading powers  $\{p_i\}$  and the array vectors  $\{a(\theta_i)\}$ . The weight vector calculator 425 calculates a maximum unique vector of the transmission correlation matrix, normalizes it, and sets the normalized maximum unique vector as a weight vector
- 10  $w_k$  to the transmission beam generator 403 for the next transmission.

The forward processor 400 encodes and modulates a transmission message through the encoder 401 and the modulator 402. The transmission beam generator 403 forms a transmission beam according to the weight vector received

15 from the weight vector calculator 425 to transmit the modulated transmission message. The transmission beam is upconverted in the RF module 404 and radiates into the air via the antenna array 405.

Though the base station returns to a reception mode, transmission and

20 reception are concurrent in the base station and the above operation repeats.

FIG. 9 is a flowchart illustrating the operations of the base station and the mobile station shown in FIG. 4. Referring to FIG. 9, the base station sets a time point and a weight vector to initial values ( $k=0$  and  $w[0]$ ) in step 601 and

25 the mobile station is also initialized in step 651.

In steps 603 and 605, the base station encodes and modulates a transmission message through the forward processor 400, forms a transmission

beam based on the weight vector, and transmits the transmission beam on a forward link. In steps 607 to 611, the base station increases the time point  $k$  and waits for the unit time  $D$  until it receives a receiver signal. While awaiting receipt of the reverse signal, the base station performs other operations.

5

Upon receipt of the forward signal in step 653, the mobile station separates the paths from which the forward signal arrives through the forward processor 430. In steps 657 to 661, the mobile station demodulates the forward signal for each path and combines the demodulated signals through the forward  
10 processor 430 and decodes the combined signal, thereby recovering a received message. In steps 663 to 669, the mobile station estimates forward fading information for each path, encodes the estimated forward fading information, and transmits the encoded forward fading information on a reverse channel through the reverse processor 440. Then, the mobile station returns to step 653 to await  
15 receipt of a next forward signal.

Upon receipt of the reverse signal in step 611, the base station separates the paths from which the reverse signal arrives through the reverse processor 410 in step 613. In step 621, the base station controls the forward fading power  
20 calculator 422 to select one of the four embodiments for generation of a weight vector. The base station controls the array vector calculator 423 to estimate an array vector  $\{a(\theta_i)\}$  for each path in step 615.

Selection of the embodiments of the present invention depends on the  
25 length of the feedback delay time  $D$  and the movement speed of the mobile station. If the feedback delay time  $D$  is relatively short and the mobile station travels at a low speed, a forward fading power is calculated by choosing the first embodiment of the present invention, a basic type in step 623.

If the feedback delay time  $D$  is long and the mobile station travels at a low speed, the forward fading power is calculated by choosing the second embodiment of the present invention, a prediction type 625.

5 If the movement speed of the mobile station exceeds a threshold, use of the basic type or the prediction type may deteriorate performance drastically. In this case, a blind forward beam formation method can be a desirable candidate. Therefore, the third embodiment (a basic mixed type) or the fourth embodiment (a prediction mixed type) can be selectively used according to the movement  
10 speed of the mobile station. In the basic mixed type, a choice made between the basic type and the blind forward beam formation method, and in the prediction mixed type, a choice is made between the prediction type and the blind forward beam formation method. In step 627, the forward fading power is calculated in a selected type according to the third embodiment of the present invention and, in  
15 step 629 it is calculated in a selected type according to the fourth embodiment of the present invention.

A detailed description of the operation of calculating the forward fading power  $p_i$  for each path according to the first to fourth embodiments of the present  
20 invention will be given below.

After the array vector and forward fading power for each path are calculated, a transmission correlation matrix  $G$  is calculated in step 631. In step 633, a maximum unique vector of the transmission correlation matrix  $G$  is  
25 calculated and normalized, thereby updating the weight vector for use in forming a transmission beam that transmits a next transmission message.

The mobile station estimates the forward fading information and feeds back it to the base station. Then, the base station generates a weight vector by  
30 estimating the forward fading information, a reverse fading power, and a Doppler

frequency received on a reverse link and forms a transmission beam based on the weight vector. For formation of the transmission beam, the forward fading power calculator 422 operates according to one of the four embodiments according to the feedback delay time D and the movement speed of the mobile station.

#### First Embodiment (Basic Type)

A transmit antenna array system according to the first embodiment of the present invention is used when the feedback delay time D is 0 or relatively short and the mobile station travels at a low speed. This transmit antenna array system is referred to as a basic type. FIG. 5 is a block diagram of the transmit antenna array system according to the first embodiment and FIG. 10 is a flowchart illustrating a forward fading power calculating operation according to the first embodiment.

15

Referring to FIGs. 5 and 10, the path divider 501 of the rake receiver 412 separates a reverse signal for each path, the demodulator 502 in each finger demodulates the reverse signal for each path, and the path combiner 503 combines all finger outputs appropriately in steps 711 and 713. In step 719, the decoder 413 decodes the combined signal, thereby recovering a received message.

Meanwhile, a forward fading decoder 511 obtains forward fading information that was received from the mobile station with a delay of the unit time D,  $\{\beta_i^F[k-D]\underline{a}(\theta_i)^H \underline{w}\}$  or  $\{|\beta_i^F[k-D]\underline{a}(\theta_i)^H \underline{w}|\}$  and a forward fading extractor 512 extracts a forward fading coefficient  $\beta_i[k-D]$  or  $|\beta_i[k-D]|$  from the forward fading information in step 715. Here,  $\{\underline{a}(\theta_i)^H \underline{w}\}$  is a value that the base station can know in advance. F represents forward, k is the current time point, and i is a path index ( $i = 1, \dots, M$ ). In step 717, the base station regards

the forward fading coefficient  $\beta_i[k-D]$  or  $|\beta_i[k-D]|$  as received at the current time point despite the time delay of D and each power calculator 509 calculates forward fading power  $\{p_i\} = \{|\beta_i^F[k]|\}$  for each path.

- 5 Each array vector calculator 423 calculates an array vector from the reverse signal received from the demodulator 502. Then the transmission correlation matrix calculator 424 calculates a transmission correlation matrix G using the forward fading powers and the array vectors. The weight vector calculator 425 calculates a maximum unique vector from the transmission  
10 correlation matrix G, normalizes it, and sets the normalized maximum unique vector as a weight vector  $w[k]$  for transmission at the next time point.

#### Second Embodiment (Prediction type)

- When the feedback delay time D is rather long, the prediction type can  
15 be used which has a means for predicting the current forward fading coefficient from previous feedback forward fading information. A transmit antenna array system according to the second embodiment of the present invention is shown in FIG. 6 and its operation is illustrated in FIG. 11. While any predictor may be used with the same effect for this transmit antenna array system, it is assumed  
20 that a linear predictor is provided.

- Referring to FIGs. 6 and 11, the path divider 501 of the rake receiver 412 separates a reverse signal for each path, the demodulator 502 in each finger demodulates a corresponding reverse signal, and the path combiner 503  
25 combines all finger outputs appropriately in steps 811 and 813. In step 821, the decoder 413 decodes the combined signal, thereby recovering a received message.

Meanwhile, the forward fading decoder 511 obtains forward fading information received from the mobile station with a delay of the unit time D,



$\{\beta_i^F[k-D] \underline{a}(\theta_i)^H \underline{w}\}$  or  $\{|\beta_i^F[k-D] \underline{a}(\theta_i)^H \underline{w}|\}$  and the forward fading extractor 512 extracts a forward fading coefficient  $\beta_i[k-D]$  or  $|\beta_i[k-D]|$  from the forward fading information in step 815. The extracted forward fading coefficient is stored in a memory 513.

5

Sub AG  
The previous forward fading information is read from the memory 513. A group of V delayed forward fading coefficients  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \dots, \beta_i^F[k-D-V+1]\}$  or  $\{|\beta_i^F[k-D]|, |\beta_i^F[k-D-1]|, \dots, |\beta_i^F[k-D-V+1]|\}$  are formed from the previous 10 forward fading information.

In step 817, each reverse fading estimator 506 estimates a reverse fading coefficient  $\{\beta_i^R\}$  for each path, each average power calculator 507 calculates an average power of the reverse fading coefficients  $\{E|\beta_i^R|^2\}$  for each path, and each 15 Doppler frequency estimator 505 estimates a Doppler frequency  $\{f_{D,i}\}$  for each path.

Sub A7  
In step 819, each current forward fading estimator 508 receives the forward fading coefficient, the average reverse fading power and the Doppler 20 frequency obtained by reverse fading estimation for each path and estimates a current forward fading for each path, and each power calculator 509 calculates forward fading power for each path. The current forward fading estimator 508 forms the group of V delayed forward fading coefficients  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \dots, \beta_i^F[k-D-V+1]\}$  or the group of V delayed 25 forward fading severities  $\{|\beta_i^F[k-D]|, |\beta_i^F[k-D-1]|, \dots, |\beta_i^F[k-D-V+1]|\}$  from the previous forward fading information read from the memory 513.

5 In the case of the forward fading coefficient group, the current forward fading estimator 508 estimates the current forward fading coefficient  $\{\beta_i^F[k]\}$  using  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \varphi, \beta_i^F[k-D-V+1]\}$ ,  $\{E|\beta_i^R|^2\}$ , and  $\{f_{D,i}\}$  for a corresponding path by the linear prediction method shown in Eq. 16, Eq. 17, and Eq. 18. On the other hand, in the case of the forward fading severity group, the current forward fading estimator 508 estimates the current forward fading severity  $\{\beta_i^F[k]\}$  using  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \varphi, \beta_i^F[k-D-V+1]\}$ ,  $\{E|\beta_i^R|^2\}$ , and  $\{f_{D,i}\}$  for a corresponding path by the linear prediction method shown in Eq. 20, Eq. 21, and Eq. 22.

10

The power calculator 509 calculates a forward fading power  $\{p_i\} = \{|\beta_i^F|^2\}$  for the corresponding path based on the forward fading coefficient.

15 The array vector calculator 423 calculates an array vector from the reverse signal of the corresponding path received from the demodulator 502. Then the transmission correlation matrix calculator 424 calculates a transmission correlation matrix  $G$  using the forward fading powers and the array vectors. The weight vector calculator 425 calculates a maximum unique vector from the transmission correlation matrix  $G$ , normalizes it, and sets the normalized  
20 maximum unique vector as a weight vector  $w[k]$  for transmission at the next time point.

### Third Embodiment (Basic Mixed Type)

25 When the feedback delay time  $D$  is 0 or relatively short, the first embodiment shows good performance until the movement speed of the mobile station reaches a threshold. However, once the mobile station travels at a speed over the threshold, the performance drastically decreases. To overcome this

problem, the blind forward beam formation method can be used when it is determined that the mobile station travels at a speed over the threshold. In the third embodiment, the basic type and the blind forward beam formation method are selectively used according to the movement speed of the mobile station. This  
 5 scheme is referred to as a basic mixed forward beam formation method.

FIG. 7 is a block diagram of a transmit antenna array system according to the third embodiment of the present invention and FIG. 12 is a flowchart illustrating the operation of a forward fading power calculator in the transmit  
 10 antenna array system according to the third embodiment of the present invention.

Referring to FIGs. 7 and 12, the path divider 501 of the rake receiver 412 separates a reverse signal for each path, the demodulator 502 in each finger demodulates a reverse signal, and the path combiner 503 combines all finger  
 15 outputs appropriately in steps 911 and 913. In step 927, the decoder 413 decodes the combined signal, thereby recovering a received message.

Meanwhile, the forward fading decoder 511 obtains forward fading information received from the mobile station with a delay of the unit time  $D$ ,  
 20  $\{\beta_i^F[k-D]\underline{a}(\theta_i)^H \underline{w}\}$  or  $\{|\beta_i^F[k-D]\underline{a}(\theta_i)^H \underline{w}|\}$  and the forward fading extractor 512 extracts a forward fading coefficient  $\beta_i[k-D]$  or  $|\beta_i[k-D]|$  from the forward fading information in step 915. Here,  $\{\underline{a}(\theta_i)^H \underline{w}\}$  is a value that the base station can know in advance.  $F$  represents forward,  $k$  is the current time point, and  $i$  is a path index ( $i = 1, \dots, M$ ). In step 917, the base station regards the  
 25 forward fading coefficient  $\beta_i[k-D]$  or  $|\beta_i[k-D]|$  as received at the current time point despite the time delay of  $D$  and each power calculator 509 calculates a forward fading power  $\{|\beta_i^F|^2\}$  for each path.

Simultaneously, each reverse fading estimator 506 estimates a reverse fading coefficient for each path from a reverse signal received from the demodulator 502, each average power calculator 507 calculates an average reverse fading power  $\{E|\beta_i^R|^2\}$  for each path, and each Doppler frequency  
 5 estimator 505 estimates a Doppler frequency for each path in step 919.

In step 921, a selector 510 selects  $\{|\beta_i^F|^2\}$  or  $\{E|\beta_i^R|^2\}$  based on the Doppler frequency. Specifically, if the Doppler frequency is less than a predetermined threshold, it is determined that the mobility of the mobile station  
 10 is low in step 921 and the forward fading power  $\{|\beta_i^F|^2\}$  is selected in step 923. On the other hand, if the Doppler frequency is greater than or equal to the threshold, it is determined that the mobility of the mobile station is high in step 921 and the average reverse fading power  $\{E|\beta_i^R|^2\}$  is selected and output as  $\{p_i\}$  in step 925.

15

Each array vector calculator 423 calculates an array vector from the reverse signal of each path received from the demodulator 502. Then the transmission correlation matrix calculator 424 calculates a transmission correlation matrix  $G$  using the forward fading powers and the array vectors. The  
 20 weight vector calculator 425 calculates a maximum unique vector from the transmission correlation matrix  $G$ , normalizes it, and sets the normalized maximum unique vector as a weight vector  $w[k]$  for transmission at the next time point.

#### 25 Fourth Embodiment (Prediction mixed Type)

When the feedback delay time  $D$  is rather long, the second embodiment shows good performance until the movement speed of the mobile station reaches a threshold. However, once the mobile station travels at a speed over the

threshold, the performance drastically decreases. To overcome this problem, the blind forward beam formation method can be used when it is determined that the mobile station travels at a speed over the threshold. In the fourth embodiment, the prediction type and the blind forward beam formation method are selectively  
 5 used according to the movement speed of the mobile station. This scheme is referred to as a prediction mixed forward beam formation method.

FIG. 8 is a block diagram of a transmit antenna array system according to the fourth embodiment of the present invention and FIG. 13 is a flowchart  
 10 illustrating the operation of a forward fading power calculator in the transmit antenna array system according to the fourth embodiment of the present invention.

Referring to FIGs. 8 and 13, the path divider 501 of the rake receiver 412  
 15 separates a reverse signal for each path, the demodulator 502 in each finger demodulates a corresponding reverse signal, and the path combiner 503 combines all finger outputs appropriately in steps 1011 and 1012. In step 1027, the decoder 413 decodes the combined signal, thereby recovering a received message.

20

Meanwhile, the forward fading decoder 511 obtains forward fading information received from the mobile station with a delay of the unit time  $D$ ,  $\{\beta_i^F[k-D]\underline{a}(\theta_i)^H \underline{w}\}$  or  $\{|\beta_i^F[k-D]\underline{a}(\theta_i)^H \underline{w}|\}$  and the forward fading extractor 512 extracts a forward fading coefficient  $\beta_i[k-D]$  or  $|\beta_i[k-D]|$  from the  
 25 forward fading information in step 1013. The extracted forward fading coefficient is stored in the memory 513.

Simultaneously, each reverse fading estimator 506 estimates a reverse fading coefficient  $\{\beta_i^R\}$  for each path from a reverse signal received from the

demodulator 502, each average power calculator 507 calculates an average reverse fading power  $\{E|\beta_i^R|^2\}$  for each path, and each Doppler frequency estimator 505 estimates a Doppler frequency  $\{f_{D,i}\}$  for each path in step 1015.

5 In step 1017, each current forward fading estimator 508 receives the forward fading coefficient, the average reverse fading power, the Doppler frequency and estimates a current forward fading for each path. That is, each current forward fading estimator 508 reads the previous forward fading information from the memory 513 and forms a group of V delayed forward  
 10 fading coefficients  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \dots, \beta_i^F[k-D-V+1]\}$  or a group of V delayed forward fading severities  $\{|\beta_i^F[k-D]|, |\beta_i^F[k-D-1]|, \dots, |\beta_i^F[k-D-V+1]|\}$  from the previous forward fading information.

15 In the case of the forward fading coefficient group, the current forward fading estimator 508 estimates the current forward fading coefficient  $\{|\beta_i^F[k]|\}$  using  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \dots, \beta_i^F[k-D-V+1]\}$ ,  $\{E|\beta_i^R|^2\}$ , and  $\{f_{D,i}\}$  for the corresponding path by the linear prediction method shown in Eq. 16, Eq. 17, and Eq. 18. On the other hand, in the case of the forward fading severity group,  
 20 the current forward fading estimator 508 estimates the current forward fading severity  $\{|\beta_i^F[k]|\}$  using  $\{\beta_i^F[k-D], \beta_i^F[k-D-1], \dots, \beta_i^F[k-D-V+1]\}$ ,  $\{E|\beta_i^R|^2\}$ , and  $\{f_{D,i}\}$  for a corresponding path by the linear prediction method shown in Eq. 20, Eq. 21, and Eq. 22.

25 Each power calculator 509 calculates a forward fading power  $\{|\beta_i^F|^2\}$  for each path based on the forward fading coefficient. In step 1021, the selector 510

selects  $\{|\beta_i^F|^2\}$  or  $\{E|\beta_i^R|^2\}$  using the Doppler frequency. Specifically, if the Doppler frequency is less than a predetermined threshold, it is determined that the mobility of the mobile station is low in step 1021 and the forward fading power  $\{|\beta_i^F|^2\}$  is selected in step 1023.

5

On the other hand, if the Doppler frequency is greater than or equal to the threshold, it is determined that the mobility of the mobile station is high in step 1021 and  $\{E|\beta_i^R|^2\}$  is selected and output as  $\{p_i\}$  in step 1025.

10 Each array vector calculator 423 in the finger calculates an array vector from the reverse signal of each path received from the demodulator 502. Then the transmission correlation matrix calculator 424 calculates a transmission correlation matrix  $G$  using the forward fading powers and the array vectors. The weight vector calculator 425 calculates a maximum unique vector from the  
15 transmission correlation matrix  $G$ , normalizes it, and sets the normalized maximum unique vector as a weight vector  $w[k]$  for transmission at the next time point.

In the mobile communication system with a transmission antenna array  
20 device of the present invention as described above, since a mobile station feeds back forward fading information to a base station, the base station can form a transmission beam more reliably. As a result, system capacity is increased, communication quality is improved, and the transmission power of the mobile station is saved.

25

While the invention has been shown and described with reference to certain preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without

departing from the spirit and scope of the invention as defined by the appended claims.

11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65  
66  
67  
68  
69  
70  
71  
72  
73  
74  
75  
76  
77  
78  
79  
80  
81  
82  
83  
84  
85  
86  
87  
88  
89  
90  
91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
1000  
1001  
1002  
1003  
1004  
1005  
1006  
1007  
1008  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1060  
1061  
1062  
1063  
1064  
1065  
1066  
1067  
1068  
1069  
1070  
1071  
1072  
1073  
1074  
1075  
1076  
1077  
1078  
1079  
1080  
1081  
1082  
1083  
1084  
1085  
1086  
1087  
1088  
1089  
1090  
1091  
1092  
1093  
1094  
1095  
1096  
1097  
1098  
1099  
1100  
1101  
1102  
1103  
1104  
1105  
1106  
1107  
1108  
1109  
1110  
1111  
1112  
1113  
1114  
1115  
1116  
1117  
1118  
1119  
1120  
1121  
1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1180  
1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239  
1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298  
1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357  
1358  
1359  
1360  
1361  
1362  
1363  
1364  
1365  
1366  
1367  
1368  
1369  
1370  
1371  
1372  
1373  
1374  
1375  
1376  
1377  
1378  
1379  
1380  
1381  
1382  
1383  
1384  
1385  
1386  
1387  
1388  
1389  
1390  
1391  
1392  
1393  
1394  
1395  
1396  
1397  
1398  
1399  
1400  
1401  
1402  
1403  
1404  
1405  
1406  
1407  
1408  
1409  
1410  
1411  
1412  
1413  
1414  
1415  
1416  
1417  
1418  
1419  
1420  
1421  
1422  
1423  
1424  
1425  
1426  
1427  
1428  
1429  
1430  
1431  
1432  
1433  
1434  
1435  
1436  
1437  
1438  
1439  
1440  
1441  
1442  
1443  
1444  
1445  
1446  
1447  
1448  
1449  
1450  
1451  
1452  
1453  
1454  
1455  
1456  
1457  
1458  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1470  
1471  
1472  
1473  
1474  
1475  
1476  
1477  
1478  
1479  
1480  
1481  
1482  
1483  
1484  
1485  
1486  
1487  
1488  
1489  
1490  
1491  
1492  
1493  
1494  
1495  
1496  
1497  
1498  
1499  
1500  
1501  
1502  
1503  
1504  
1505  
1506  
1507  
1508  
1509  
1510  
1511  
1512  
1513  
1514  
1515  
1516  
1517  
1518  
1519  
1520  
1521  
1522  
1523  
1524  
1525  
1526  
1527  
1528  
1529  
1530  
1531  
1532  
1533  
1534  
1535  
1536  
1537  
1538  
1539  
1540  
1541  
1542  
1543  
1544  
1545  
1546  
1547  
1548  
1549  
1550  
1551  
1552  
1553  
1554  
1555  
1556  
1557  
1558  
1559  
1560  
1561  
1562  
1563  
1564  
1565  
1566  
1567  
1568  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1590  
1591  
1592  
1593  
1594  
1595  
1596  
1597  
1598  
1599  
1600  
1601  
1602  
1603  
1604  
1605  
1606  
1607  
1608  
1609  
1610  
1611  
1612  
1613  
1614  
1615  
1616  
1617  
1618  
1619  
1620  
1621  
1622  
1623  
1624  
1625  
1626  
1627  
1628  
1629  
1630  
1631  
1632  
1633  
1634  
1635  
1636  
1637  
1638  
1639  
1640  
1641  
1642  
1643  
1644  
1645  
1646  
1647  
1648  
1649  
1650  
1651  
1652  
1653  
1654  
1655  
1656  
1657  
1658  
1659  
1660  
1661  
1662  
1663  
1664  
1665  
1666  
1667  
1668  
1669  
1670  
1671  
1672  
1673  
1674  
1675  
1676  
1677  
1678  
1679  
1680  
1681  
1682  
1683  
1684  
1685  
1686  
1687  
1688  
1689  
1690  
1691  
1692  
1693  
1694  
1695  
1696  
1697  
1698  
1699  
1700  
1701  
1702  
1703  
1704  
1705  
1706  
1707  
1708  
1709  
1710  
1711  
1712  
1713  
1714  
1715  
1716  
1717  
1718  
1719  
1720  
1721  
1722  
1723  
1724  
1725  
1726  
1727  
1728  
1729  
1730  
1731  
1732  
1733  
1734  
1735  
1736  
1737  
1738  
1739  
1740  
1741  
1742  
1743  
1744  
1745  
1746  
1747  
1748  
1749  
1750  
1751  
1752  
1753  
1754  
1755  
1756  
1757  
1758  
1759  
1760  
1761  
1762  
1763  
1764  
1765  
1766  
1767  
1768  
1769  
1770  
1771  
1772  
1773  
1774  
1775  
1776  
1777  
1778  
1779  
1780  
1781  
1782  
1783  
1784  
1785  
1786  
1787  
1788  
1789  
1790  
1791  
1792  
1793  
1794  
1795  
1796  
1797  
1798  
1799  
1800  
1801  
1802  
1803  
1804  
1805  
1806  
1807  
1808  
1809  
1810  
1811  
1812  
1813  
1814  
1815  
1816  
1817  
1818  
1819  
1820  
1821  
1822  
1823  
1824  
1825  
1826  
1827  
1828  
1829  
1830  
1831  
1832  
1833  
1834  
1835  
1836  
1837  
1838  
1839  
1840  
1841  
1842  
1843  
1844  
1845  
1846  
1847  
1848  
1849  
1850  
1851  
1852  
1853  
1854  
1855  
1856  
1857  
1858  
1859  
1860  
1861  
1862  
1863  
1864  
1865  
1866  
1867  
1868  
1869  
1870  
1871  
1872  
1873  
1874  
1875  
1876  
1877  
1878  
1879  
1880  
1881  
1882  
1883  
1884  
1885  
1886  
1887  
1888  
1889  
1890  
1891  
1892  
1893  
1894  
1895  
1896  
1897  
1898  
1899  
1900  
1901  
1902  
1903  
1904  
1905  
1906  
1907  
1908  
1909  
1910  
1911  
1912  
1913  
1914  
1915  
1916  
1917  
1918  
1919  
1920  
1921  
1922  
1923  
1924  
1925  
1926  
1927  
1928  
1929  
1930  
1931  
1932  
1933  
1934  
1935  
1936  
1937  
1938  
1939  
1940  
1941  
1942  
1943  
1944  
1945  
1946  
1947  
1948  
1949  
1950  
1951  
1952  
1953  
1954  
1955  
1956  
1957  
1958  
1959  
1960  
1961  
1962  
1963  
1964  
1965  
1966  
1967  
1968  
1969  
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
1979  
1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1990  
1991  
1992  
1993  
1994  
1995  
1996  
1997  
1998  
1999  
2000  
2001  
2002  
2003  
2004  
2005  
2006  
2007  
2008  
2009  
2010  
2011  
2012  
2013  
2014  
2015  
2016  
2017  
2018  
2019  
2020  
2021  
2022  
2023  
2024  
2025  
2026  
2027  
2028  
2029  
2030  
2031  
2032  
2033  
2034  
2035  
2036  
2037  
2038  
2039  
2040  
2041  
2042  
2043  
2044  
2045  
2046  
2047  
2048  
2049  
2050  
2051  
2052  
2053  
2054  
2055  
2056  
2057  
2058  
2059  
2060  
2061  
2062  
2063  
2064  
2065  
2066  
2067  
2068  
2069  
2070  
2071  
2072  
2073  
2074  
2075  
2076  
2077  
2078  
2079  
2080  
2081  
2082  
2083  
2084  
2085  
2086  
2087  
2088  
2089  
2090  
2091  
2092  
2093  
2094  
2095  
2096  
2097  
2098  
2099  
2100  
2101  
2102  
2103  
2104  
2105  
2106  
2107  
2108  
2109  
2110  
2111  
2112  
2113  
2114  
2115  
2116  
2117  
2118  
2119  
2120  
2121  
2122  
2123  
2124  
2125  
2126  
2127  
2128  
2129  
2130  
2131  
2132  
2133  
2134  
2135  
2136  
2137  
2138  
2139  
2140  
2141  
2142  
2143  
2144  
2145  
2146  
2147  
2148  
2149  
2150  
2151  
2152  
2153  
2154  
2155  
2156  
2157  
2158  
2159  
2160  
2161  
2162  
2163  
2164  
2165  
2166  
2167  
2168  
2169  
2170  
2171  
2172  
2173  
2174  
2175  
2176  
2177  
2178  
2179  
2180  
2181  
2182  
2183  
2184  
2185  
2186  
2187  
2188  
2189  
2190  
2191  
2192  
2193  
2194  
2195  
2196  
2197  
2198  
2199  
2200  
2201  
2202  
2203  
2204  
2205  
2206  
2207  
2208  
2209  
2210  
2211  
2212  
2213  
2214  
2215  
2216  
2217  
2218  
2219  
2220  
2221  
2222  
2223  
2224  
2225  
2226  
2227  
2228  
2229  
2230  
2231  
2232  
2233  
223